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ANTIPROTON-PROTON RESONANT LIKE CHANNELS IN $J/\psi \to \gamma p\bar{p}$ DECAYS*

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The BES collaboration has recently observed a strong enhancement close to the proton-antiproton, $p\bar{p}$ threshold in the J/ψ decays into $\gamma p\bar{p}$. Such a structure can be explained by a traditional nucleon-antinucleon, $N\bar{N}$, model. The near threshold $^{11}S_0$ bound state and/or the well-established $^{13}P_0$ resonant state found in this $N\bar{N}$ interaction can adequately describe the BES data.

Keywords: $p\bar{p}$ quasi-bound states; traditional $N\bar{N}$ model; radiative J/ψ decays.

1. Introduction

Existence of near threshold bound states or resonances in nucleon-antinucleon, $N\bar{N}$, interaction is a challenging matter[1]. Low-energy scattering could indicate the presence of such structures by determining the scattering lengths for $^{2I+1,2S+1}L_J$ states. Here I denotes the isospin (0 or 1), S the spin (0 or 1), L the angular momentum and J the total angular momentum. An alternative is to use formation experiments. At the Beijing electron-positron collider, the BES collaboration has observed a resonant-like behavior in the $p\bar{p}$ invariant mass spectrum from radiative $J/\psi \to \gamma p\bar{p}$ decays[2]. The present work studies the physics of slow $p\bar{p}$ pairs produced in J/ψ decays, using J^{PC} conservation, P being the parity and C the charge conjugation. Here we rely on the Paris $N\bar{N}$ potential model.

2. Close to Threshold Proton-Antiproton Final State Model

2.1. *The low-energy nucleon-antinucleon interaction*

The Paris $N\bar{N}$ interaction is built up from a state dependent optical potential. The long range, $r > 1$ fm, real part is obtained by G-parity transformation of the

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Paris NN potential, the two-pion exchange of which is calculated via dispersion relations from pion-nucleon scattering data. The short ranges, $r < 1$ fm, real part and absorptive part, with a form suggested by calculation of $N\bar{N}$ annihilation into two mesons or resonances, are both determined through fit to the $\bar{N}N$ data. In the different versions, the short range parameters are readjusted by fitting to new data. The Paris 82 potential[3], fitted to pre-LEAR (CERN) data, mainly elastic $\bar{p}p$ (isospin 1 + isospin 0) data , has a χ^2/data of 2.8 for 915 data. The Paris 94 potential[4] uses LEAR data, in particular $\bar{p}p \to \bar{n}n$ ($I = 1 - I = 0$) data, and has a χ^2/data of 2.46 for 3295 data. In the Paris 99 version[5], more recent LEAR data, in particular for $\bar{p}p \to \bar{n}n$, were used leading to a χ^2/data of 2.95 for 3814 data. The Paris 04 model[6] is constrained by fitting to the 1999 data plus the scattering lengths extracted from antiprotonic hydrogen and deuterium data[7] and to the total $\bar{n}p$ cross-section[8]. It has χ^2/data = 3.19 for 3934 data.

2.2. *Allowed slow $p\bar{p}$ final states*

The J^{PC} conservation ($J^{PC} = 1^{--}$ for J/ψ) limits the number of slow $p\bar{p}$ final states. These correspond to pairs of small $M_{p\bar{p}} - 2m_p$ with $M_{p\bar{p}}$ being the invariant $p\bar{p}$ mass and m_p the proton mass. The allowed states are listed in Table 1. Some two-particle analogues[10] are listed in the second column. The last column indicates the relative angular momentum between γ or π and the $p\bar{p}$ pair h. The BES experiment[2] angular distribution favors a pseudoscalar $^1S_0$ or a scalar $^3P_0$ h final state.

Table 1. The slow $p\bar{p}$ pairs states permitted in the radiative $J/\psi \to \gamma p\bar{p}$.

decay mode	analogue	$J^{PC}[\gamma \text{ or } \pi]$	$J^{PC}[p\bar{p}]$	$h(p\bar{p})$	relative ℓ
$\gamma p\bar{p}(^1S_0)$	$\gamma\eta(1444)$	1^{--}	0^{-+}	pseudoscalar	1
$\gamma p\bar{p}(^3P_0)$	$\gamma f_0(1710)$	1^{--}	0^{++}	scalar	0
$\gamma p\bar{p}(^3P_1)$	$\gamma f_1(1285)$	1^{--}	1^{++}	pseudovector	0

2.3. *Specific final-state interaction model*

The transition amplitude from a channel i to a channel f, in a multichannel system at low energy described by a S-wave K matrix, can be written as $T_{if} = A_{if}(1 + iq_f A_{ff})^{-1}$. Here A_{if} is a transition length, A_{ff} the scattering length in the channel f and q_f the momentum in this channel[10]. The f channel scattering amplitude can also be expressed as $T_{ff} = A_{ff}(1 + iq_f A_{ff})^{-1}$. For a P wave close to threshold, $A_{ff} = A^P_{ff} q_f^2$ and $A_{if} = A^P_{if} q_f$ where A^P_{ff} is the scattering volume. Up to terms in q_f^2 one has $T_{if} = (A_{if}/A_{ff})T_{ff} = CT_{ff}/q_f^L = Ct_L$. The quantity $C = A_{if} q_f^L / A_{ff}$ represents the unknown formation amplitude and $|t_L|^2 = |T_{ff}/q_f^L|^2$ is the final state interaction factor in a given $p\bar{p}$ partial wave. In terms of the phase shifts δ_L and inelasticities η_L of a given $N\bar{N}$ interaction one has $t_L = \left(\eta_L e^{2i\delta_L} - 1\right)/(2iq_f^{2L+1})$. The function C is parametrized by $|C(x)|^2 = q_f(c_0 + c_1 x)$ where $x = M_{p\bar{p}} - 2m_p$ and $q_f = [x(m_p + x/4)]^{1/2}$.

3. Results and Conclusions

The final state interaction factors $|t_L|^2$ for the $^1S_0$ and $^3P_0$ states and for the different versions of the Paris $N\bar{N}$ are compared to the BES data [2] in Figs. 1 and 2. The c_0 and c_1 parameters are determined by requiring $|T_{if}|^2$ of Paris 04 to be close to the events distribution as given in Fig. 3 of Ref. 2 at $x = 7$ MeV and $x = 66.2$ MeV. For $^1S_0$, $c_0 = 1.18599$, $c_1 = 0.00299$ and for $^3P_0$, $c_0 = 2.5206$, $c_1 = 0.0269$. As seen in Fig. 1, the data is well reproduced by the Paris 04 $N\bar{N}$ interaction. This interaction has a $^{11}S_0$ bound state located at $x = -4.8$ MeV and with a width Γ of 52.5 MeV. Paris 99 has also a bound state at $x = -69$ MeV with $\Gamma = 46$ MeV. There are no bound states for Paris 94 or Paris 82. All Paris models have a $^{13}P_0$ resonance of mass ~ 1876 MeV and $\Gamma \sim 10$ MeV. They all reproduce the near threshold BES enhancement as seen in Fig. 2.

In conclusion, the near threshold $p\bar{p}$ enhancement seen in BES collaboration[2] can find a natural explanation from a traditional model of $\bar{p}p$ interaction. The $^{11}S_0$ bound state[6] needs confirmation. The well established $^{13}P_0$ resonance originates from the strong attraction of the one-pion exchange[11]. Each of these states gives a reasonable representation of the BES radiative $J/\psi \to \gamma p\bar{p}$ decay data. They correspond to the S or P wave Breit Wigner resonance functions considered by BES collaboration in their fit to the data[2].

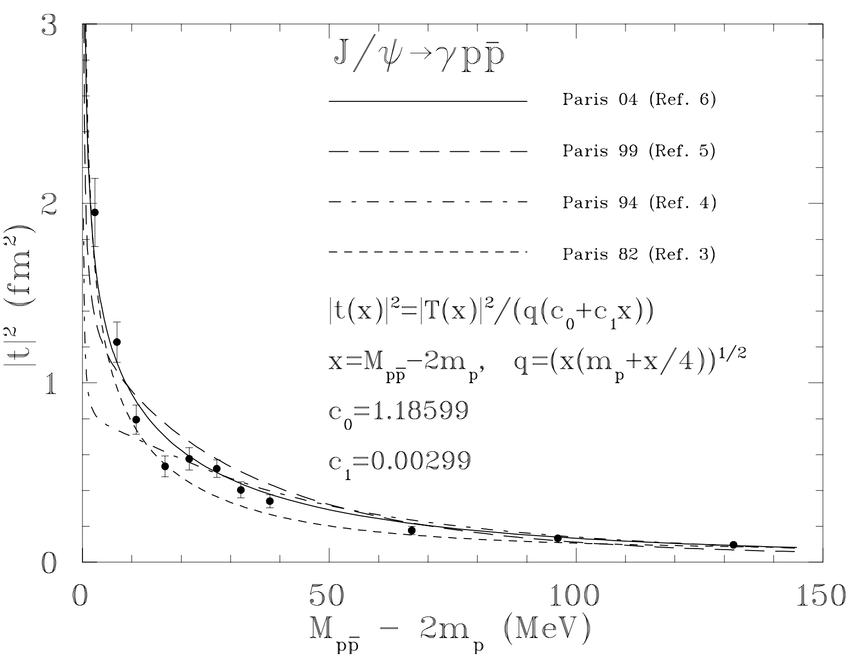

Fig. 1. The $^1S_0$ final state factor compared to BES data[2]

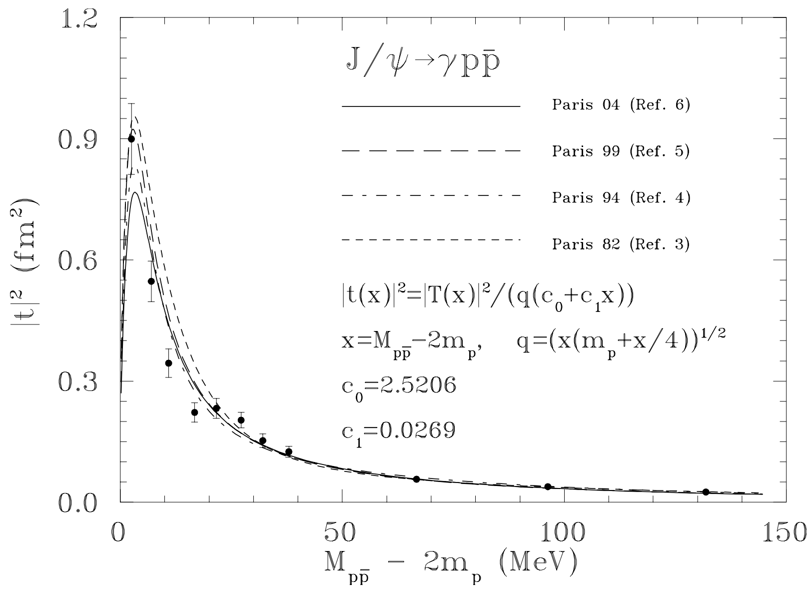

Fig. 2. The $^3P_0$ final state factor compared to BES data[2]

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